

A COMPARISON BETWEEN ASYMMETRIC ROLLING AND ACCUMULATIVE ROLL BONDING AS MEANS TO REFINE THE GRAIN STRUCTURE OF AN Al-Mg-Si ALLOY

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Summary

The possibility of refining the grain structure of a commercial Al-Mg-Si alloy was evaluated using asymmetric rolling (ASR) and accumulative roll bonding (ARB) in the severe plastic deformation (SPD) regime. Bars of annealed alloy having a thickness of 10 mm were asymmetrically rolled down to a thickness of 0,23 mm with a laboratory rolling mill featuring the possibility of independently modifying the rotational speed of its two rolls. The effect of the rolling temperature was investigated by tests in the range 150- 250 °C. A parallel campaign was also conducted to investigate the effects of warm accumulative roll bonding of the same alloy and in the same temperature range. These tests were carried out on annealed samples of 1 mm thickness. The experimental characterization (both mechanical and microstructural) demonstrated that asymmetric rolling and accumulative roll bonding can readily promote the achievement of ultrafine grained structures in Al-Mg-Si alloys.

Keywords: aluminum alloys, severe plastic deformation, ultrafine grained materials.

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Introduction

It has been widely proved that a reduction in grain size corresponds to enhanced mechanical properties of metallic alloys [1]. The generation of Ultrafine Grained (UFG) materials, with a grain size in the submicrometer scale, thus leads to materials with higher strength and improved ductility at room temperature compared to coarse grained materials, as well as better formability at high temperature (under appropriate strain rate and temperature superplastic behavior can easily occur) [2]. One of the available mechanisms that allows strong refining of the grain structure is continuous dynamic recrystallization (cDRX) [3]. According to this process, the material experiences the formation of deformation/microshear bands for low and medium equivalent strain, while at higher degree of strain, in the Severe Plastic Deformation (SPD) regime, grain subdivision occurs due to the increase in boundary misorientation, eventually leading to high-angle grain boundaries.

Alternatively, many other thermo-mechanical processes exist giving the possibility to refine the grain structure by discontinuous recrystallization. However, the attempts to reduce grain size in commercial aluminum alloys exploiting this phenomenon have encountered many difficulties due to its high stacking faults energy [4]. This characteristic strongly facilitates the phenomenon of recovery instead of recrystallization. Several SPD techniques have been developed in last decades in order to impart high amounts of equivalent strain to materials, either at a lab or at the industrial scale, by exploiting cDRX mechanism. In the former group, it is possible to cite Equal Channel Angular Extrusion (ECAE) and High Pressure Torsion (HPT). In the latter group it is possible to mention Asymmetric Rolling (ASR) and Accumulative Roll Bonding (ARB). Rolling processes are among the most attractive processes for SPD since they can be industrially exploited with modest modifications of the rolling mill. The aim of this work is to compare two rolling techniques (ASR and ARB) as a means to refine the grain structure of a 6082-type aluminum alloy.

In Asymmetric rolling, different peripheral speeds of the upper and lower rolls are adopted and the sheet is thus subjected to enhanced shear deformation, in addition to compression strain. It has been suggested that this would readily promote the development of ultrafine grains. Cui and Ohori [5] investigated the structure evolution of high-purity aluminium during room temperature ASR with reduction of thickness exceeding 90% and asymmetry ratio of 1,4 (the mismatch speed ratio between upper and lower rolls). They suggested that the evolution of microstructure results from the development of high-angle grain boundaries (HAGBs) due to the simultaneous action of compression and shear strain. Jin and Lloyd [6,7] also performed ASR followed by annealing on a commercial 5754 aluminum alloy. After appropriate processing with an asymmetry ratio of 2, they were able to produce grain sizes as small as 1 micrometer featuring a tensile response comparable to that of ultrafine-grained alloys produced by other SPD methods.

ARB is a discontinuous process that keeps the geometry and size of the billets constant. It has been shown [8,9] that the formation of UF grains during intense plastic deformation is the simultaneous action of grain subdivision and recovery of the deformed structure. An important concern when exploiting Accumulative Roll Bonding technique is that is possible to achieve a reasonably homogeneous microstructure and texture using a small number of passes.

Materials and experimental procedures

Commercial bars of a type 6082 Al alloy having a thickness of 10 mm and width of 40 mm were annealed at 450°C for 30 minutes and cold rolled down to a thickness of 0,23 mm. This overall reduction was achieved by a multipass procedure with no intermediate annealing treatments. A laboratory rolling mill (roll diameter 150 mm, width 200 mm) featuring the possibility of independently modifying the rotational speed of its two rolls was adopted for this purpose. The rolling schedule imposed a reduction of thickness of 20% at each step and the rotation of the billet along its longitudinal axis before each pass. The asymmetry ratio adopted was 1.4 on the basis of previous studies [10]. To improve the formability of the alloy and to investigate the effects of warm rolling, the process was conducted at 250 °C, with an inter-pass heating of 5 minutes. For accumulative roll bonding, bars of the same material were conventionally rolled down to 1 mm thickness and then annealed with the same heat treatment of the original samples. Special surface preparation was performed to improve sheet bonding: wire brushing and acetone washing was performed before stacking the two sheets together by rivets. As for the ASR, the roll-bonding process was performed at 250 °C.

The investigation here presented is mainly focused on microhardness and microstructure as a function of rolling conditions. Microhardness measurements with a load on the indenter of 1 N were performed to evaluate mechanical properties. Microstructure analyses were carried out by scanning electron microscopy (SEM) and transmission electron microscopy (TEM). SEM and TEM samples were prepared by mechanically grinding the materials down to about 85 micrometer thickness. Final twin jet thinning was performed at 18V with a solution of 30% HNO₃ in methyl alcohol at -30°C. Results have been analyzed as a function of equivalent strain, considering a strain of 0,8 for each ARB pass (corresponding to 50% reduction in thickness) [11] and calculated according to the equation (1) for ASR [12]:

$$\epsilon = 1,155 \cdot \ln \left(\frac{h_1}{h_2} \right) \quad (1)$$

Results and discussion

In figure 1 the evolution of microhardness as a function of equivalent strain is plotted for both processes.

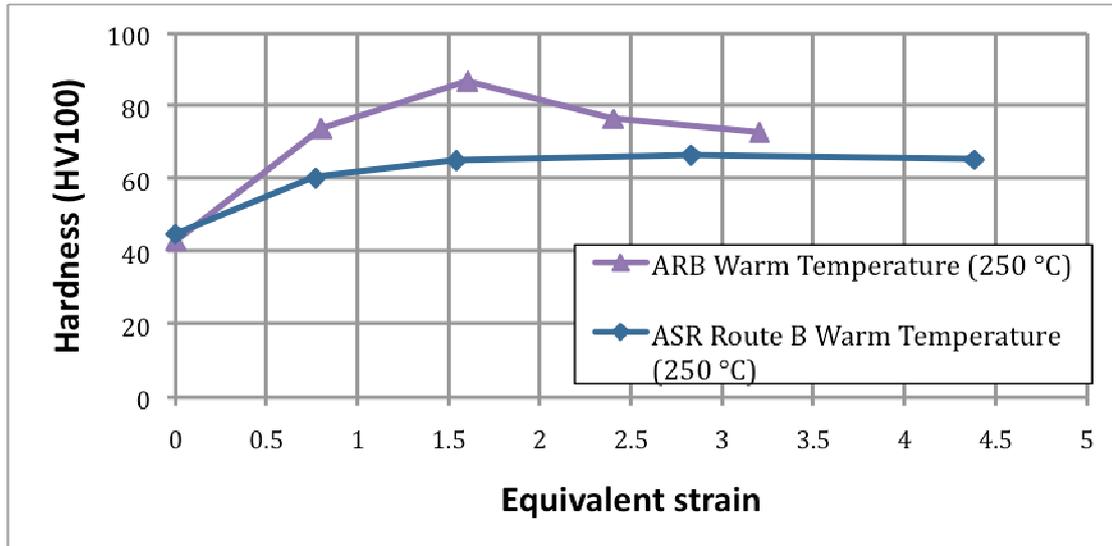


Figure 1 Evolution of microhardness as a function of equivalent strain for both ARB and ASR process at 250 °C

It is possible to see that the two curves appear quite different. While there is an initial stage of hardness increase for low and medium equivalent strains, for ARB a decrease in microhardness occurs for high levels of strain. The behaviour of asymmetrically rolled specimens is quite different: the initial increase is more moderate and reaches a maximum for equivalent strain of about 200%, then remains almost constant.

The microstructural analyses allowed understanding this behaviour considering the different structures that are formed in the first part of the process. In figure 2 two representative micrographs are shown, referring to samples with similar equivalent strain.

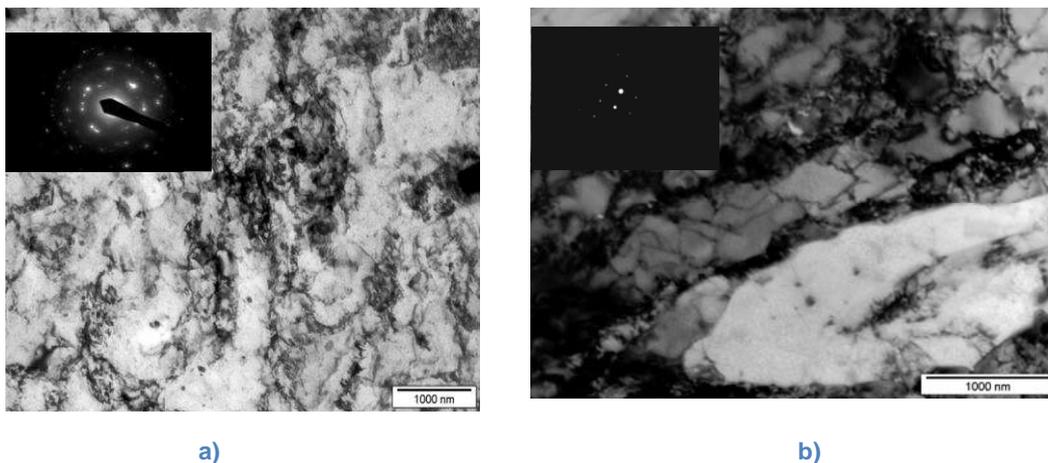


Figure 2 TEM Micrograph of ARBed a) and ASRed b) samples subjected to equivalent strain of 80% and 77% respectively

In these micrographs it is clear that asymmetrically rolled sample has the tendency to create microshear bands, while accumulative roll bonding gives rise to a more homogeneous microstructure. Furthermore, the dislocation density seems to be higher in figure 2 a) and this evidence can be a good explanation for the higher value of microhardness of the ARBed material.

Further plastic straining leads to a progressive evolution of the microstructure. While asymmetrically rolled sample tends to decrease the width of the shear bands and fragment them, the ARBed material still remains homogeneous and the apparent dislocation density increases. This behaviour is well recognized in figure 3 a) and b).

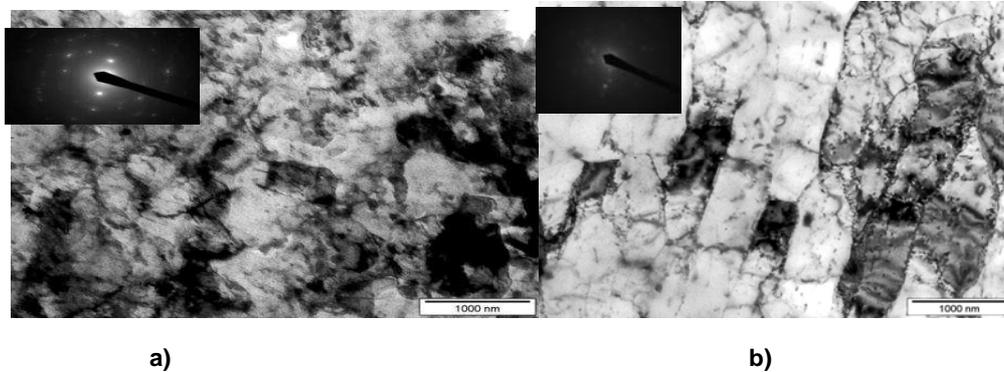


Figure 3 TEM micrographs of the rolled samples; a) ARBed sample at 160% of equivalent strain; b) ASRed sample at 154% of equivalent strain

The analysis of figure 3 a) and b) are of importance when trying to understand the different mechanical behaviour of the samples processed by the two methods at very high strains. By considering the continuous increase of dislocation density for the ARBed material, it is clearly explained why it possesses higher value of microhardness. Instead, the asymmetrically rolled material, reduces the size of microshear bands without any increase in dislocation density and this can be the reason why the curve in figure 1 has a smoother evolution.

Figure 4 refers to the last step of both rolling process. The value of equivalent strain is approximately the same (400% for accumulative roll bonding and 438% for asymmetric rolling) and the microstructures are quite similar as well. What is interesting to note is that the microstructure of ASRed material is definitely homogeneous, since the process of fragmentation already started at lower strains. Not only fragmentation, but also recovery had occurred. In particular, recovery ease the fragmentation of shear bands and this implies the reduction of dislocation density. It is possible to state that both the reduction of grain size by fragmentation and of dislocation density by recovery concur to keep the microhardness constant for high levels of equivalent strain.

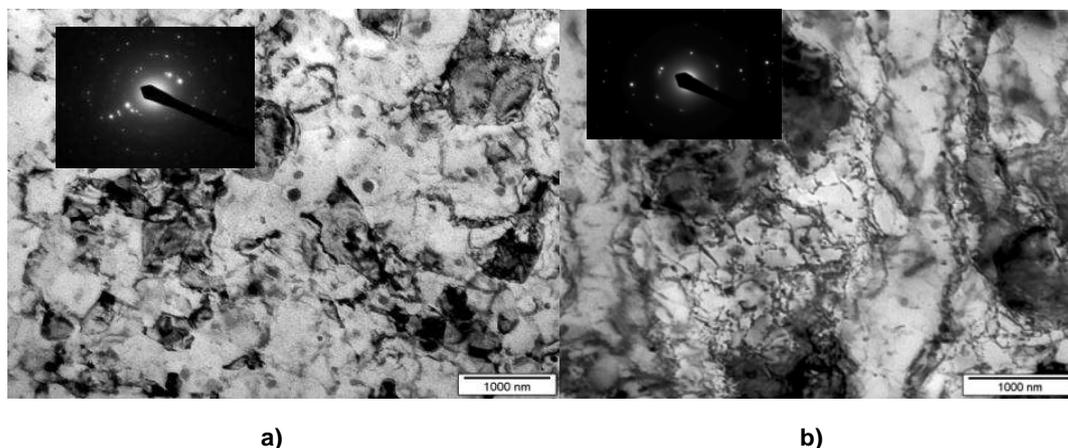


Figure 4 TEM Micrographs of a) ARBed sample at 400% of equivalent strain and b) ASRed sample at 438% of equivalent strain

Accumulative roll bonding processed material (Fig 4 a)) shows, as expected, a more homogeneous structure. The main difference with respect to the ASRed material is the dislocation density. During the process the material underwent heavy recovery and this lowers mechanical properties due to decrease in work hardening. This evolution of the two microstructures reflects the microhardness curves for both materials.

Another important feature that can be drawn for both rolling processes is the stimulation of precipitation and coarsening of second phase particles due to holding at 250 °C and possibly to enhanced diffusion related to the heavy deformation experienced. As depicted in figures 5 and 6, due to strain and temperature, the fraction and size of second-phase particles increase dramatically, preventing clear observations of the grains with the technique of backscattered electron channelling. Furthermore, coarsening of the particles clearly occur by increasing the number of passes (i.e. the strain).

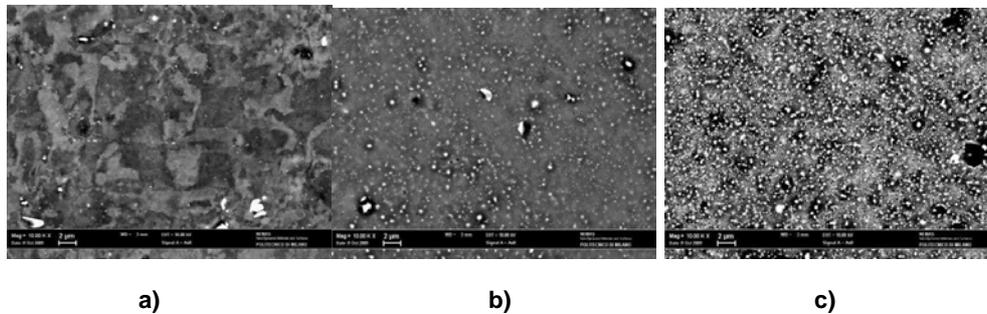


Figure 5 SEM BSE micrographs of ARBed samples with equivalent strain a) 80%, b) 160%, c) 400%

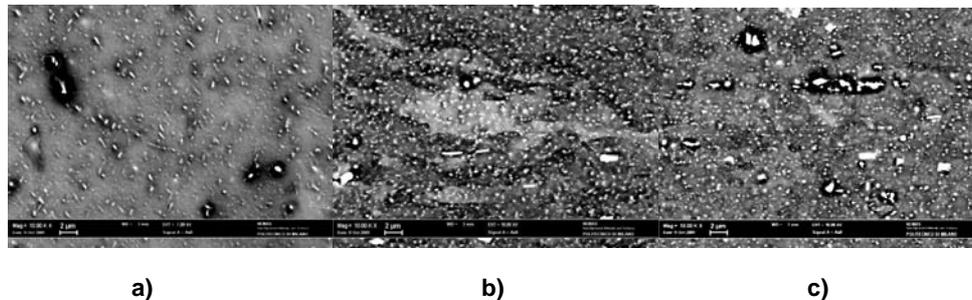


Figure 6 SEM BSE micrographs of asymmetrically rolled samples with equivalent strain of a) 77%, b) 154% and c) 438%

Finally, figure 6 confirms the formation of microshear bands for the asymmetrically rolled material at the beginning of the rolling process, detected also by a different technique. For the last sample (6 c)) a homogeneous microstructure is highlighted.

Conclusions

The evolution of the microstructure strongly depends on the process adopted. For asymmetric rolling of the 6082 Al alloy, the first part of the process is spent to create microshear bands (up to an equivalent strain of about 150%) and to reduce their width. For higher values of equivalent strain, the material undergoes fragmentation of the microshear bands and the subsequent creation of an ultrafine structure, even at a warm temperature of 250 °C. At the end of the process, recovery and work hardening are almost balanced so that the mechanical properties do not change significantly with further strain.

Accumulative roll bonding, due to a different state of strain, does not impose a severe orientation of the grains and the microstructure generated at each pass remains fairly homogeneous. The largest part of the evolution is concentrated at the beginning of the process and the contribution of work hardening is considerable, determining a great response in terms of mechanical properties, as shown by the microhardness curve. At the end of the process, recovery is more important than work hardening so that the material shows a decrease in mechanical properties when deformed at 250 °C to very large strains.

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